26. T.R. Neuman, J.C. Glennon, and J.W. Leisch. Stopping Sight Distance--An Operational and Cost-Effectiveness Analysis. U.S. Department of Transportation, Sept. 1981.
27. G.H. Robinson. Visual Search for Automobile Drivers. Human Factors, Vol. 14, No. 4, 1972, pp. 315-323.
28. J.E. Baerwald, ed. Traffic Engineering Handbook. ITE, Washington, DC, 1965.
29. L. Rach. Traffic Signals. In Transportation and Traffic Engineering Handbook, 2nd ed. (W.S. Homburger, ed.), ITE, Washington, DC, 1982, pp. 737-782.
30. Traffic Control Devices Handbook, An Operating Guide. FHWA, revised ed., Draft Rept., 1980.
31. D. Gazis, R. Herman, and A. Maradudin. The Problem of the Amber Signal Light in Traffic Flow. Traffic Engineering, July 1960, pp. 19-26.
32. P.L. Olson and R.W. Rothery. Driver Response to the Amber Phase of Traffic Signals. Traffic Engineering, Feb. 1962, pp. 17-29.
33. R.H. Wortman and J.S. Matthias. An Evaluation of Driver Behavior at Signalized Intersections. Arizona Transportation Research Center, Phoenix, Draft Rept. ATTI-82-1, May 1982.
34. D.F. King. Guidelines for Uniformity in Traffic Signal Design Configurations. NCHRP, Research Results Digest 97, Dec. 1977, 8 pp.

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Abridgment

Corrections to Driver Characteristic Specifications and Standard Formulations for Intersection Sight Distance

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This report documents an evaluation of the American Association of State Highway and Transportation Officials standards for intersection sight distance and how they are affected by driver characteristics. The study involved the development of a population profile for the driver characteristic perception-reaction time, and the calculation of the sensitivity of each standard to realistic changes in the driver characteristic. The study found that, for case I intersection sight distance, the driver is not provided sufficient time or distance to take evasive action from an opposing vehicle, and for case II, adequate sight distance in order to stop before the intersection is not provided despite the intent of the standard to enable such an action. Proper formulations are developed in the paper and proposed as revisions. The effect of these revisions on current standard intersection sight distances is described and quantified. In addition, recommendations are made to increase the perception-reaction-time value for case I from 2.0 to 3.4 s and for case II from 2.5 to 3.4 s.

The 1965 American Association of State Highway Officials (AASHO) Blue Book, A Policy on Geometric Design of Rural Highways (1), and its draft revised versions (2) present standards for adequate sight distance at intersections. Abridged analyses of the interrelations between characteristics and the sight-distance standards for cases I and II follow. Included in these analyses are investigations into the appropriateness of the current standard formulations.

CASE I: ENABLING VEHICLES TO ADJUST SPEED

Current Standard

At an intersection where no approach leg is controlled by stop signs, yield signs, or traffic signals, a driver of a vehicle who approaches the intersection must be provided adequate sight distance both to perceive the potentially conflicting movement of a crossing vehicle and to take the necessary countermeasure. The American Association of State Highway and Transportation Officials (AASHTO) (2) formula for computing the minimum allowable sight distance on each leg is as follows:

$$D = 1.467V(PRAT) \quad (1)$$

where

D = minimum sight triangle distance (ft),
V = vehicle velocity (mph), and
PRAT = perception-reaction-action time (s).

The formulation assumes that the appropriate minimum distance from an intersection, at the point where the driver first observes a vehicle approaching on an intersecting road, is that which is covered during both the driver's perception and reaction time (which includes 1 s in which the speed of the vehicle is adjusted by the driver's reaction). AASHTO recommends the use of between 2.5 and 3.0 s as the value for the perception-reaction-action time: 1.5-2.0 s for perception and reaction and 1.0 s for the action (acceleration or deceleration).

Driver Characteristic

The perception-reaction process in this case is the ability of a driver to perceive a vehicle moving across his or her path, judge its trajectory in relation to his or her vehicle, and then decide whether some speed adjustment is necessary to avoid collision. A literature review did not uncover any studies on how long it takes drivers to perform this overall task. In the absence of any empirical research, estimates of the actual distribution of perception-reaction times for the driving population have to be based on a sum of the times for the components of the process determined from the available literature.

If one were to model the driver's task for this situation (i.e., before the vehicle actually accelerates or decelerates), the following steps would likely be considered:

1. Driver picks up (through peripheral vision) an object moving toward the intersection;
2. After a latency period, eye or head movement or both detects the object;

3. Object is recognized as vehicle;
4. Opposing vehicle's speed and time to reach intersection are estimated;
5. Decision is made on whether deceleration or acceleration is required; and
6. Decided action is initiated (e.g., foot moves to brake pedal).

This is a relatively simple model of the driver's action and does not consider any overlapping of the discrete steps. Nonetheless, by assigning time values to each of the steps and then summing, at least a reasonable upper value can be established. Values for each of the above steps can be approximated by using current research literature, as is detailed by McGee and Hooper (3). The resulting estimated total values for various percentiles of the driving population are as follows: current specification, 2.0 s; 50th percentile, 2.6 s; 85th percentile, 3.4 s; and 95th percentile, 4.0 s.

CASE II: ENABLING VEHICLES TO STOP

Current Standard

The second case of intersection sight-distance requirements cited by AASHTO (2) deals with the situation in which "it is assumed that the operator of a vehicle on either highway must be able to see the intersection and the intersecting highway in sufficient time to stop the vehicle before reaching the intersection." Simply stated, the AASHTO policy requires that a driver of a vehicle moving toward an uncontrolled intersection be able to see a vehicle approaching the intersection from another leg when each vehicle is situated at its stopping-sight distance from the intersection.

The AASHTO (2) formulation for stopping-sight distance is as follows:

$$SSD = 1.47(RT)V + V^2/30(f \pm g) \qquad (2)$$

where

SSD = stopping-sight distance (ft),
RT = perception-brake-reaction time (s),
V = initial vehicle velocity (mph),
f = coefficient of friction between tires and roadway, and
g = grade of roadway (ft/ft).

Driver Characteristic

The case II intersection sight-distance standard is based directly on the driver characteristic perception-brake-reaction time. The AASHTO specification for stopping-sight distance perception-brake-reaction time is 2.5 s. However, in this application, the driver is required to perform a more complex set of actions than is required in sighting and stopping for a stationary object in the roadway. The driver needs more time to pick up the other moving vehicle through peripheral vision and to move the head or eyes or both to detect the object. The decisionmaking component of the perception-brake-reaction task is also more complex because the driver must first evaluate the velocity of the other vehicle and the potential for a collision before deciding to take a particular evasive action. The actual perception-decision-reaction process that a driver must follow in a case II situation is similar to the process described earlier for case I situations. Therefore, the case II perception-reaction time approximates the values listed previously for case I. The values range from an estimated 2.6 s for the 50th percentile to an estimated 4.0 s for the 95th percentile. The suggested estimated 85th percentile value of 3.4 s is well above the specification value of 2.5 s.

The computed case II intersection sight distances are listed in Table 1 for the current specification value and for the estimated 50th, 85th, and 95th percentile drivers. The percentage differences between these values and the current rounded stopping-sight distance standard values are also given in Table 1. For example, assuming a perception-brake-reaction time value of 3.4 s, the calculated desirable intersection sight distance would be 18 percent greater than the current standard value at 30 mph and nearly 10 percent greater at 70 mph.

It should be emphasized that these values for perception-brake-reaction time are to be considered estimates. They were determined by adding values, in some instances estimates themselves, of discrete components of the perception-brake-reaction time. It cannot be stated with certainty that these values do represent the true distribution of the driving public because they were based on relatively small sample sizes and less-than-actual driving conditions.

Critique of Standard

The AASHO (1) definition of the conditions that describe case II (enabling vehicles to stop) states that the "operator of a vehicle on either highway must be able to see the intersection and the intersecting highway in sufficient time to stop the vehi-

Table 1. Computed case II intersection sight distances based on various values of perception-brake-reaction time.

	Design Stopping-Sight Distance[a]		Computed Stopping-Sight Distance at Following RT Values							
			RT = 2.5 s (specification)		RT = 2.6 s (50th percentile)		RT = 3.4 s (85th percentile)		RT = 4.0 s (95th percentile)	
Design Speed (mph)	SSD (ft)	Condition	SSD (ft)	Increase Above Standard (%)	SSD (ft)	Increase Above Standard (%)	SSD (ft)	Increase Above Standard (%)	SSD (ft)	Increase Above Standard (%)
30	200	Minimum	177	-12	181	-9.5	214	7.0	239	20
	200	Desirable	196	-2.0	200	0	235	18	262	31
40	275	Minimum	267	-2.9	272	-1.1	315	15	346	26
	325	Desirable	313	-3.7	319	-1.8	366	13	401	23
50	375	Minimum	376	0.3	383	2.1	435	16	473	26
	475	Desirable	461	-2.9	468	-1.5	527	11	571	20
60	525	Minimum	501	-4.6	509	3.0	570	8.6	616	17
	650	Desirable	634	-2.5	643	-1.1	713	9.7	766	18
70	625	Minimum	613	-1.9	622	-0.5	690	10	741	19
	850	Desirable	840	-1.2	850	0	932	9.6	994	17

[a] Design values from AASHO (1).

Figure 1. Illustration of inadequacy of case II formulation.

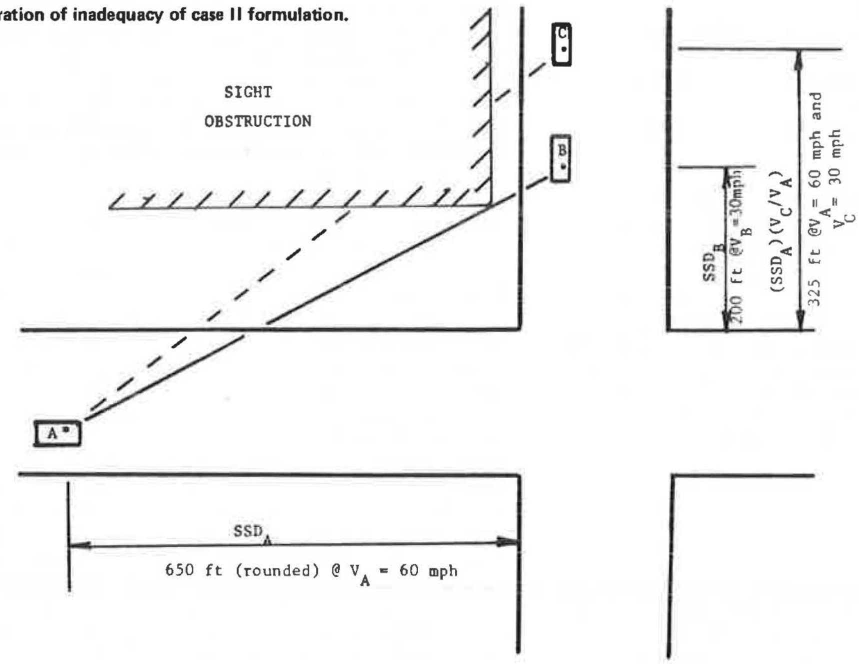

Table 2. Minimum distance of vehicle B from intersection based on suggested revised methodology for case II intersection sight distance.

Design Speed of Vehicle A (mph)	Minimum Distance of Vehicle B from Intersection[a] (ft) at Following Velocities					AASHTO SSD[b] (ft)	
	V_B = 30 mph	V_B = 40 mph	V_B = 50 mph	V_B = 60 mph	V_B = 70 mph	V_A	V_B
30	196	261	326	391	457	200	200
40	235	313	392	470	548	325	325
50	277	369	461	553	646	475	475
60	317	423	528	634	739	650	650
70	360	480	600	720	840	850	850

[a]Calculated with the suggested revised formulation: $D_B = [1.467(RT)V_A + V_A^2/30(f \pm g)] (V_B/V_A)$. Derivation and explanation of the formula is provided in the text. Values for V_A, V_B, and SSD are based on full (desirable) velocities. Perception-brake-reaction time is assumed to be 2.5 s—the specification for these calculations.
[b]The listed stopping-sight-distance values are the "rounded for design" values provided by AASHTO (2).

cle before reaching the intersection." There are three different relative approach patterns for two vehicles at an uncontrolled intersection: either vehicle A arrives first, or vehicle B arrives first, or they arrive simultaneously. According to the above definition, the case II sight distance should enable a driver confronted with the collision scenario to bring the vehicle to a complete stop before reaching the intersection. As is explained below, the AASHTO standards for stopping-sight distance do not provide this adequate sight distance in some cases. Instead, the AASHTO standards will sometimes place the driver in a situation where a speed adjustment must be made to avoid a collision but where stopping distance is not available; in other words, we are back to case I (enabling vehicles to adjust speed).

In terms of the sketch in Figure 1, the AASHTO case II intersection sight distance requires that the driver of vehicle A be able to see vehicle B, each of which is situated at its respective stopping-sight distance from the intersection. Immediately on sighting vehicle B, the driver of vehicle A reacts and brings vehicle A to a stop before reaching the intersection. However, if vehicle B did not exist, the driver of vehicle A would pass the SSD_A point without perceiving the presence of a vehicle on the other leg of the intersection. For example, vehicle C cannot be seen by the driver of vehicle A; if both vehicle A and vehicle C proceed at a constant speed (60 and 30 mph, respectively, in Figure 1), they will arrive at the intersection simultaneously. Thus, in reality, the situation is a version of case I, where a vehicle is not given enough distance to stop but instead is provided distance to only decelerate to avoid the other vehicle.

It is recommended that the case II methodology be revised so that the driver of a vehicle located at its stopping-sight distance from an uncontrolled intersection be provided a direct line of sight to an approaching vehicle located the greater of the two distances described below:

1. The stopping-sight distance that corresponds to the latter vehicle's velocity, or
2. The distance at which the latter vehicle would be in order for the two vehicles to collide if the speeds of both were maintained.

In general, the distance for the slower-approaching vehicle would need to be increased. Table 2 lists computed minimum distances for various combinations of approach velocities.

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Operation. The contents reflect our views and we are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the U.S. Department of Transportation.

REFERENCES

1. A Policy on Geometric Design of Rural Highways. AASHO, Washington, DC, 1965.
2. A Policy on the Geometric Design of Highways and Streets. AASHTO, Washington, DC, Review Draft 3, 1982.
3. H.W. McGee and K.G. Hooper. Highway Design and Operations Standards Affected by Driver Characteristics. FHWA, Draft Rept. FHWA-RD-83-015, 1983.

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Visual Complexity and Sign Brightness in Detection and Recognition of Traffic Signs

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The effects of sign luminance on the detection and recognition of traffic-control devices are mediated through contrast with the immediate surround. In addition, complex visual scenes are known to degrade visual performance with targets well above the visual threshold. A laboratory study was conducted to determine ways of measuring visual complexity and to assess the capability of changes in sign luminance to offset decrements in performance that result from added complexity. Positive results were found for warning, construction, and stop signs but not for the black-on-white regulatory sign. Regression equations that use complexity factors, contrast, and target variables suggested that, in complex scenes, complexity is a more significant determinant of sign detection than brightness or contrast. A field study was also conducted to determine if these findings could be observed in terms of real-world driver performance. The effects of visual complexity were observed in the field, and increasing sign brightness improved sign detection and recognition under specific conditions.

The role of sign brightness and the visual complexity of the nighttime highway environment in the detection and recognition of traffic signs was studied in both laboratory and field situations. The laboratory study permitted control over a large number of highway scenes that varied in the amount of visual clutter. The field study was undertaken to determine whether sign brightness and visual complexity had an observable effect on driver behavior.

LABORATORY STUDY

The primary objective of the laboratory study was the development of a metric for visual complexity based on target-independent characteristics of the visual field. In this regard, the study addressed the question of whether a sign location that causes sign-recognition problems can be identified from measurements or observations of the location itself. A secondary objective of the laboratory study was to determine whether increases in sign brightness offset decrements in visual performance that result from the visual complexity of the location.

The detection of a visual target, such as a traffic sign, is influenced by the characteristics of the target and by the contrast of these target characteristics with similar dimensions of the surround. For example, the attention-getting value of a target increases as

1. The target's brightness increases (1,2),
2. The brightness contrast between the target and its surround increases (2-7),
3. The brightness contrast between different parts of the target increases (e.g., sign legend to background) (2,5),
4. The target's size increases relative to other stimuli in the visual field (2,8,9),
5. The shape of the target contrasts with noise items (10), and
6. The target's hue contrasts with noise (5,11).

In addition to the effects of target characteristics, the characteristics of a target's surround also influence the likelihood of target detection. Specifically, several basic studies suggest that target conspicuity increases as

1. The number of noise elements in the visual field decreases (12-18),
2. The overall density of noise items in the visual field decreases (19-21),
3. The density of noise items immediately adjacent to the target decreases (22),
4. The distance between the target and noise increases (15-17,23),
5. The target is located further from the center of the visual field than the noise (versus when the target is located closer to the center of the visual field than the noise) (23-27),
6. The number of irrelevant classes of stimuli in the visual field decreases (i.e., as the visual field becomes more homogenous) (28), and
7. The variability within each irrelevant class of stimuli decreases (21).

Because the majority of the studies listed above reflect basic research efforts that often use abstract targets located within relatively sterile visual matrices, operational definitions that facilitate measurement of these dimensions in complex highway scenes have not been established. One applied study (29) that did use photographs of actual road scenes as stimuli found that background complexity had a substantial negative effect on detection. The components of background complexity, however, were not evaluated.

The experimental methodology of the laboratory study attempted to simulate real-world variation in visual complexity via photographic stimuli. In order to simulate a driver's search for signing in-